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A potential global boundary stratotype section and point (GSSP) for the Tarentian Stage, Upper Pleistocene, from the Taranto area (Italy): Results and future perspectives

Alessandra Negri [a,*], Alessandro Amorosi [b], Fabrizio Antonioli [c], Adele Bertini [d], Fabio Florindo [e], Pontus C. Lurcock [e], Stefano Marabini [b], Giuseppe Mastronuzzi [f], Eleonora Regattieri [g], Veronica Rossi [b], Daniele Scarponi [b], Marco Taviani [h], Giovanni Zanchetta [g], Gian Battista Vai [b]

[a] Dipartimento di Scienze della Vita e dell'Ambiente, Università Politecnica delle Marche, Via Brecce Bianche, Ancona, Italy
[b] Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Via Zamboni 67, University of Bologna, Bologna, Italy
[c] ENEA, UTMEA, Via Anguillarese 301, Roma, Italy
[d] Dipartimento di Scienze della Terra, University of Florence, Via la Pira 4, Firenze, Italy
[e] Istituto Nazionale di Geofisica e Vulcanologia (INGV), Via di Vigna Murata 605, 00143 Roma, Italy
[f] Dipartimento di Scienze della Terra e Geoambientali, University of Bari, Via Orabona, Bari, Italy
[g] Dipartimento di Scienze della Terra, University of Pisa, Via Santa Maria 53, Pisa, Italy
[h] Istituto di Scienze Marine ISMAR, CNR, Via Gobetti 101, Bologna, Italy

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We present new data collected at the Fronte composite section near Taranto, where the Upper Pleistocene marine sedimentary succession is continuously exposed. Above a fossiliferous calcarenite yielding the "Senegalese" fauna, and abundant *Cladocora*, the ^{230}Th/U age of which is consistent with Marine Isotope Stage (MIS) 5, a 6.25 m thick pelitic unit is characterized by lithologically homogeneous marine sediments in which stable oxygen isotope, micropaleontological and palynological analyses suggest a long and undisturbed sedimentary interval across the Marine Isotope Stage (MIS) 5.5 peak (plateau). High sedimentation rates and a successful paleomagnetic pilot study indicate the probability of locating brief chronostratigraphic events useful for correlation with both continental and marine successions elsewhere. These results show the composite section to be a very promising candidate in the search for the Upper Pleistocene global boundary stratotype section and point (GSSP).

1. Introduction: the problem of the Upper Pleistocene GSSP

The chronostratigraphy of the Pleistocene Series and its geochronologically equivalent Epoch is still strongly debated. The basic principles used in subdividing the Pleistocene into chronostratigraphic units are the same as adopted for other Phanerozoic units that require boundary definitions and the designation of boundary stratotypes (Salvador, 1994). As regards the subdivision of successions, however, the Quaternary differs from the rest of the Phanerozoic: in this period, subdivision fundamentally and traditionally rests on the basis of climatic changes documented in the sedimentary record (Gibbard, 2003).

For the subdivision of the Pleistocene, a tripartite classification into Lower (Early), Middle and Upper (Late) Pleistocene as subseries has been accepted (Cowie and Bassett, 1989) and is in general use. On these principles, Cita and Castradori (1995) made a proposal after several years of research and discussion, chiefly among Italian stratigraphers, over the course of two workshops and field expeditions. They proposed a new chronostratigraphic scheme for the entire Pleistocene including old and new stages, and detailing criteria for the selection of boundary stratotypes. Among them was a proposal for a Global Boundary Stratigraphic Section and Point (GSSP) in the Taranto area, based on the extensive presence of the gastropod *Persististrombus latus* (=*Strombus bubonius*).

The subdivision proposed in Cita and Castradori (1995) (Fig. 1) was informal, and the boundary between the Middle and Upper Pleistocene has not yet been formally defined by the International Union of Geological Sciences (IUGS). However, as early as the 2nd

* Corresponding author.
E-mail addresses: a.negri@univpm.it, alessandra.negri1160@gmail.com (A. Negri).

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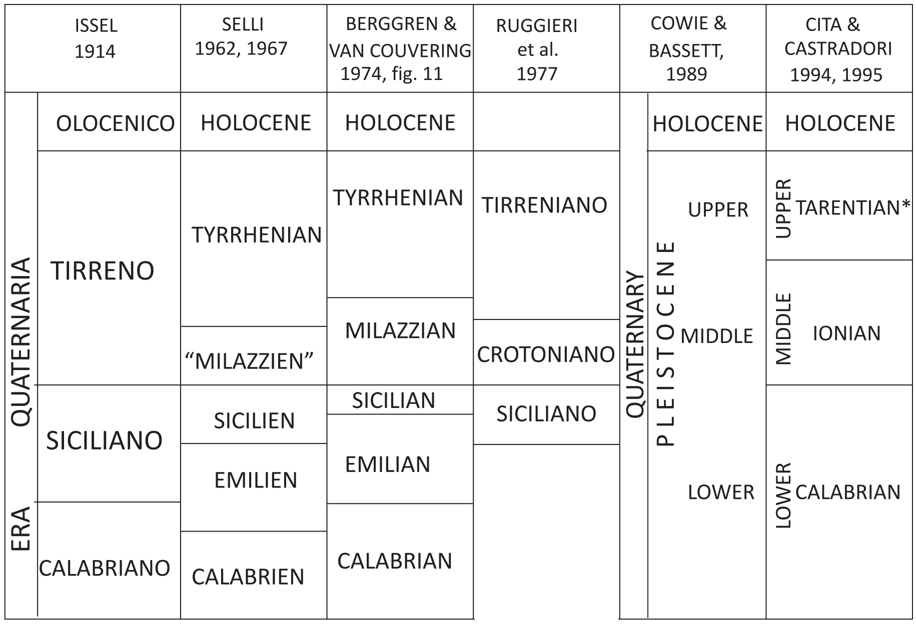

Fig. 1. Historical subdivision of the Pleistocene Epoch. "Tarantian" was the name proposed by Cita and Castradori (1994, 1995); van Couvering (1995) for the interval ranging from the MIS 6/5 boundary (0.13 Ma) or Termination II, to the Holocene, as substitute for the widely accepted Tyrrhenian. Here, we introduce the name Tarentian, from the Latin *Tarentum* for the city of Taranto, South Italy, located at the center of a wide area characterized by marine deposits of this age, including the section we studied, and suitable to host the GSSP for the Tarentian Stage and Upper Pleistocene Subseries.

INQUA Congress in Leningrad in 1932, a decision was made to define the Middle/Upper (Late) Pleistocene boundary at the base of the last interglacial, the Eemian Stage in European continental deposits (Woldstedt, 1962). As reported in Litt and Gibbard (2008) more recently, the lower boundary of the Upper (Late) Pleistocene has been placed at the base of MIS 5 by Richmond (1996), based on an unpublished proposal approved by the 12th INQUA Congress in Ottawa in 1987. This supposes a correspondence between the MIS 5.5 substage in ocean sediments and the northwest European Eemian Interglacial Stage on land (Shackleton, 1977). However, pronounced offsets between marine isotopic warm stage boundaries and forested intervals were described for MIS 5 by Sánchez Goñi et al. (1999) and Shackleton et al. (2003). In order to obviate this problem, following the INQUA agreement established 75 years ago, Gibbard (2003) proposed that the Middle/Upper Pleistocene boundary stratotype (GSSP) should be defined in the high-resolution cored succession from the Amsterdam-Terminal borehole (the Eemian Stage parastratotype; Van Leeuwen et al., 2000, Fig. 2). This proposal, having passed all the required formal steps within the International Commission on Stratigraphy, was rejected by IUGS in 2008.

After the workshop held in Bari in 1994 (Cita and Castradori, 1994, 1995), the informal proposal for the Middle Pleistocene Subseries to be identified with the Ionian Stage, and the Upper Pleistocene Subseries with the Tarentian Stage, was introduced and widely circulated (Van Couvering, 1995). The fact that these substages had the status of *nomina nuda* stimulated a group of researchers to look for a potential section for the Upper Pleistocene GSSP (Antonioli et al., 2008). A highly expanded stratigraphic succession from southern Italy (Fronte Section, in the Taranto area), unconformably overlying Middle Pleistocene marine clay deposits, was recently reported as a rare outcrop example of an uninterrupted marine sedimentary record of MIS 5e (Amorosi et al., 2014). In the present work we present new data from an adjacent section, demonstrating the Taranto area to be a very promising candidate for the Upper Pleistocene GSSP.

1.1. Upper Pleistocene marine successions outcropping in Italy

Exposed Upper Pleistocene marine sedimentary successions exceeding 1–2 m in thickness are uncommon even in the Mediterranean area, despite the widespread occurrence of sites containing reliable markers of the last interglacial sea-level highstand. A large number of sedimentary successions dated to the "Tyrrhenian/Eutyrrhenian" time interval have been recognized at different altitudes, ranging between +210 m (Strait of Corinth, Greece) and −120 m (Po Plain, Italy) with respect to modern sea level (Ferranti et al., 2006). The term "Tyrrhenian" was introduced by Issel (1914) (Fig. 1) to indicate the *Couches à Strombus* of Gignoux (1913) for the time interval between the Sicilian and the Holocene. Later, Bonifay and Mars (1959) assigned the peak of the typical *Strombus bubonius* fauna to the chronostratigraphic Eutyrrhenian subunit. The beach deposit exposed at Cala Mosca in Sardinia was proposed as the stratotype for both Tyrrhenian and Eutyrrhenian units. According to these authors, the terms "Tyrrhenian" and "Eutyrrhenian" are based on observations of exposed coastal features indicating the sea-level highstand during the last interglacial. The obvious coincidence between the Eutyrrhenian coastal sea-level highstand observations, at times supported by radiometric dating, and the MIS 5.5 sea-level data allowed correlation of the MIS 5.5 substage with the Eutyrrhenian subunit. During MIS 5.5, a warm faunal assemblage known as the "Senegalese fauna" (Gignoux, 1913), and mainly represented by molluscs (e.g., *P. latus* (Gmelin, 1791) (= *Strombus bubonius*, Lamarck, 1822), *Polinices lacteus* (Guilding 1834), *Monoplex trigonus* (Gmelin 1791), *Gemophos viverratus* (Kiener, 1834) (= *Cantharus viverratus*), *Conus ermineus* (Born, 1778) (= *Conus testudinarius* Hwass in Bruguière, 1792), *Brachidontes puniceus* (Gmelin 1791), *Hyotissa hyotis* (Linnaeus 1758), colonized the Mediterranean coasts (Ferranti et al., 2006; Sabelli and Taviani, 2014). Although some uncertainty surrounds the biostratigraphic occurrence of *P. latus* in the Western Mediterranean (Zazo et al., 1999), the fossil specimens retrieved in the central Mediterranean have been attributed to the MIS 5.5

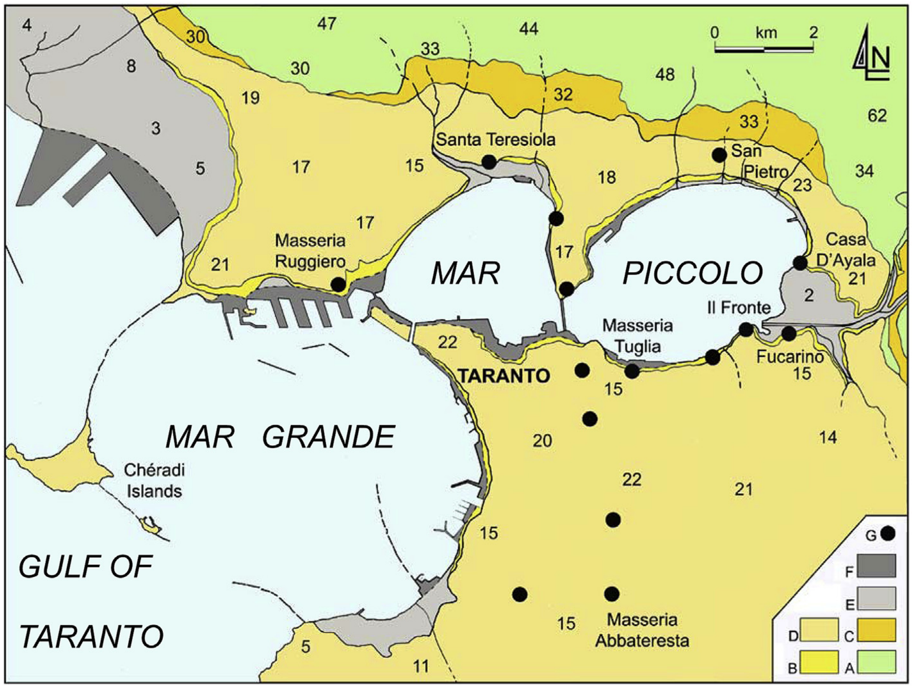

Fig. 2. Geologic–geomorphologic map showing interpretative reconstruction of the MIS 5 (D) and MIS 11? (C) marine terraces and related coastlines in the Taranto area (modified after Dai Pra and Stearns, 1977; Mastronuzzi, 2001; Belluomini et al., 2002, Amorosi et al., 2014). A, pre-Middle Pleistocene calcareous substratum; B, Lower to Middle Pleistocene pelagic sediments (Blue Clay); C, Middle Pleistocene calcareous marine deposits (MIS 11?); D, Upper Pleistocene marine deposits (MIS 5); E, Holocene alluvial and beach deposits; F, Reclaimed areas (19th and 20th centuries); G, Black dots: outcrops with "Senegalese" fauna. Numbers indicate elevation above sea level. Note that according to Dai Pra and Stearns (1977), the boundary between A and C is a paleocoastline older than 300 ka.

highstand on the basis of reliable ^{230}Th/U dating (Ferranti et al., 2006). In particular, the occurrence of *P. latus* in Italy is restricted to the Tyrrhenian and Ionian Sea coasts, whereas it has never been found along the Adriatic Sea coast.

The recent paper by Ferranti et al. (2006) offers a detailed picture of the variety of the "Tyrrhenian/Eutyrrhenian" sediments around the entire Italian peninsula, highlighting the occurrence of outcrops exceeding 10–15 m in thickness due to high seismo–tectonic activity. Within this geological context, a particularly promising zone for detecting this interval is located along the Ionian side of Apulia (southern Italy), around the city of Taranto, where several thick Upper Pleistocene (Tyrrhenian) outcrops occur (Fig. 2). One such locality (The Fronte) provides excellent exposures that have attracted scientific attention in recent decades (Dai Pra and Stearns, 1977; Hearty and Dai Pra, 1992; Belluomini et al., 2002).

Fig. 2 is based on recent surveys (Mastronuzzi, 2001; Belluomini et al., 2002; Mastronuzzi et al., 2007; Amorosi et al., 2014) that improve the first description of the extent of the marine terraces (Dai Pra and Stearns, 1977). Dai Pra and Stearns, 1977 reported two quasi-flat surfaces whose inner margins occur respectively at 28–35 and 35–55 m above sea level, the higher and more landward dated as older than 300 ka (based on four ^{230}Th/U dates yielding ages ranging from 250 to 350 ka). Such an age is consistent with MIS 11, possibly the longest (423,000–362,000 ka) and warmest interglacial of the entire Quaternary, attaining the highest-known sea-level so far (Roberts et al., 2012). These features therefore indicate a low uplift rate at least during the last 125 ka, but possibly extended up to the last 400 ka.

The first and highly accurate description of the section was given by Dai Pra and Stearns (1977) who documented a succession of blue clays in which a laminated horizon and tephra layers occur. According to these authors, an angular unconformity separates these clays from an overlying thick calcarenite, on top of which an erosional surface was identified. Dark continental sediments and "chaotic marls, probably reworked" were observed to rest above this erosional surface.

The stratigraphic description by Amorosi et al. (2014), while showing several similarities with that by Dai Pra and Stearns (1977), lists five separate lithological units above a stratigraphic unconformity placed at the top of the Blue Clay (Argille Subappennine Fm). These five units, which are the same as those used in this work and can be seen in Fig. 3 in ascending order, are as follows:

Unit 1 is a very thin, bioclastic, fine–sandy mud layer, with common oyster shells and fining-upward bioclasts in a sandy matrix. Unit 2 is made of a highly fossiliferous, homogeneous grey mud containing shallow-marine benthic foraminifera (mainly *Ammonia tepida*, *Ammonia parkinsoniana* and *Cribroelphidium* species) and the coral *Cladocora caespitosa*. Unit 3 is a cemented, fossil-rich calcarenite (regionally called *panchina*), yielding abundant *C. caespitosa*, especially in its lower part. Unit 4 is a 4.5 m-thick, reddish to greenish mud with an open-shelf meiofauna (mainly the benthic foraminifera *Bulimina marginata* and *Cibicidoides pachyderma*). Unit 5 is another fossiliferous calcarenite containing dispersed mollusc shells and *Cladocora* corallites.

No erosional surface was recognized at the top of the fossiliferous calcarenite (unit 3) bearing the "Senegalese" fauna, which instead shows continuity with the overlying marine marly sediments (unit 4). This contains a peculiar assemblage of molluscs and foraminifera, enabling the detection of the maximum flooding zone (MFZ), related by the authors to the MIS 5.5 peak. This correlation is further corroborated by ^{230}Th/U dating performed on single specimens of *C. caespitosa*, which are consistent with the MIS 5.5 substage.

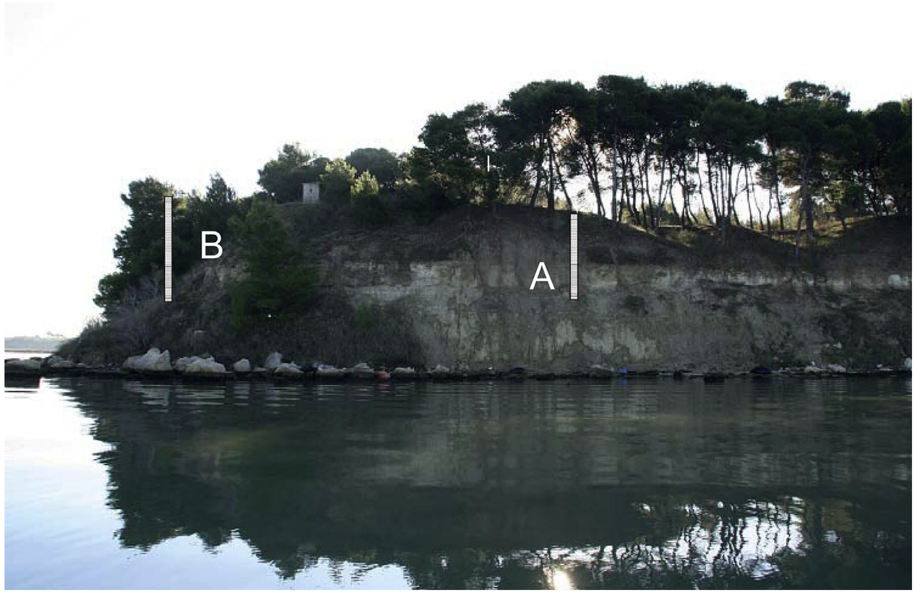

Fig. 3. The Fronte composite section. A, the Fronte section described in Amorosi et al. (2014). B, the Fronte section at the Garitta (this study).

The relatively wide Fronte outcrop has been visited by the authors on several occasions (November 2007, November 2009, October 2011), resulting in the first comprehensive contribution by Amorosi et al. (2014). In September 2012 we returned to the Fronte area, exploring a new eastern portion (Garitta) which became better exposed after an important storm event. Here we focus on new data from the additional Garitta section, located 20–30 m east of the Fronte Section as studied by Amorosi et al. (Fig. 3). At this site, the pelitic unit 4 "sandwiched" between the two fossiliferous calcarenite units is very well exposed and, probably due to local variation in the thickness of unit 5, shows a total thickness of 6.25 m.

Here, we discuss a composite section combining the previously known stratigraphic data with the newly acquired evidence from the Garitta section.

2. Materials and methods

The Fronte outcrop is located about 7 km east of Taranto, along the coastal cliff surrounding the Mar Piccolo (Figs. 1 and 2), close to the 65° *Deposito Territoriale* of the *Aeronautica Militare*, Taranto, Italy (40° 28′ 32.57″ N, 17° 18′ 48.07″ E). The section is easily accessed by land and sea, because of the proximity to the harbour, and the km-sized outcrop guarantees easy sampling for comparison. Moreover, the conservation of the outcrop site is assured by a protocol under formalization between Bari and Taranto universities and the Administration of the Italian Air Force, owner of the Fronte site.

Here, above an unconformity bounding the upper part of the Blue Clay (Argille Subappennine Fm), a continuous coastal to marine succession preserved from the subsequent lowstand dissection and erosion occurs, showing a slightly westward-dipping bedding 1 to 2 degrees as a result of basin-margin deposition. The stratigraphic section reported in this study (Fig. 4) is a stack composed of the lower part of the Fronte section (units 1–3) described in Amorosi et al. (2014), and the 6.25 m-thick silty marls (unit 4), overlain by 60 cm of fossiliferous calcarenite (unit 5), exposed at the Garitta site.

We focused our study on unit 4, from which a total of 23 samples were collected and used for high-resolution analyses of benthic and planktonic foraminifera, palynomorphs, oxygen stable isotopes and magnetic properties of sediments. In addition, one sample (black star in Fig. 4) was collected in the lower portion of the overlying unit 5, to better constrain paleoenvironmental patterns in unit 4.

The analysis of the foraminiferal fauna was undertaken on 18 samples from unit 4, spaced at 20–60 cm, and the one extra sample collected from unit 5. Following standard procedures, the samples (each approximately 150–200 g of sediment) were (i) dried at 60 °C for 8 h, (ii) soaked in water, (iii) wet sieved at 63 μm (240 mesh) and (iv) dried again. Each sample was qualitatively observed under a binocular microscope and split into small portions. At least 150–200 well-preserved specimens of benthic foraminifers were counted for each sample in the size fraction >125 μm (120 mesh), where adult specimens concentrate, and species' relative abundances (%) were finally calculated. Planktonic foraminifers were simultaneously counted as a group to calculate the planktonic/benthic ratio.

Paleoecological mollusk-derived inferences from unit 5 were made after a rapid survey of the outcropping *panchina*, performed by delimiting a 20-cm high and 40-cm wide surface on vertical outcrop exposures and noting all exposed fossils. Faunal abundance data (n) were recorded by eye as rare/sparse ($n < 4$ specimens per quadrat), common ($4 \leq n \leq 9$ specimens per quadrat), or abundant ($n > 9$ specimens per quadrat). All specimens were identified according to the lowest possible taxonomic rank (commonly genus or species). Taxonomic assignments are based on Appeltans et al. (2012).

The identification of benthic foraminiferal species observed in unit 4 and 5 relied upon original descriptions (Ellis and Messina, 1940) and several key papers and books including AGIP (1982), Kennett and Srinivasan (1983), Jorissen (1988), Hemleben et al. (1989), Sgarrella and Moncharmont Zei (1993), Fiorini and Vaiani (2001) and Milker and Schmiedl (2012). Molluscs identification was assisted by comparison with reference collections housed at the Museo di Geologia G. Capellini and Museo dell'Evoluzione (Bologna, Italy).

The paleoenvironmental interpretation of benthic foraminiferal assemblages, mainly in terms of past water depths and sea-floor oxygen-trophic conditions, relied upon the autecological characteristics of species, inferred from a series of specific papers

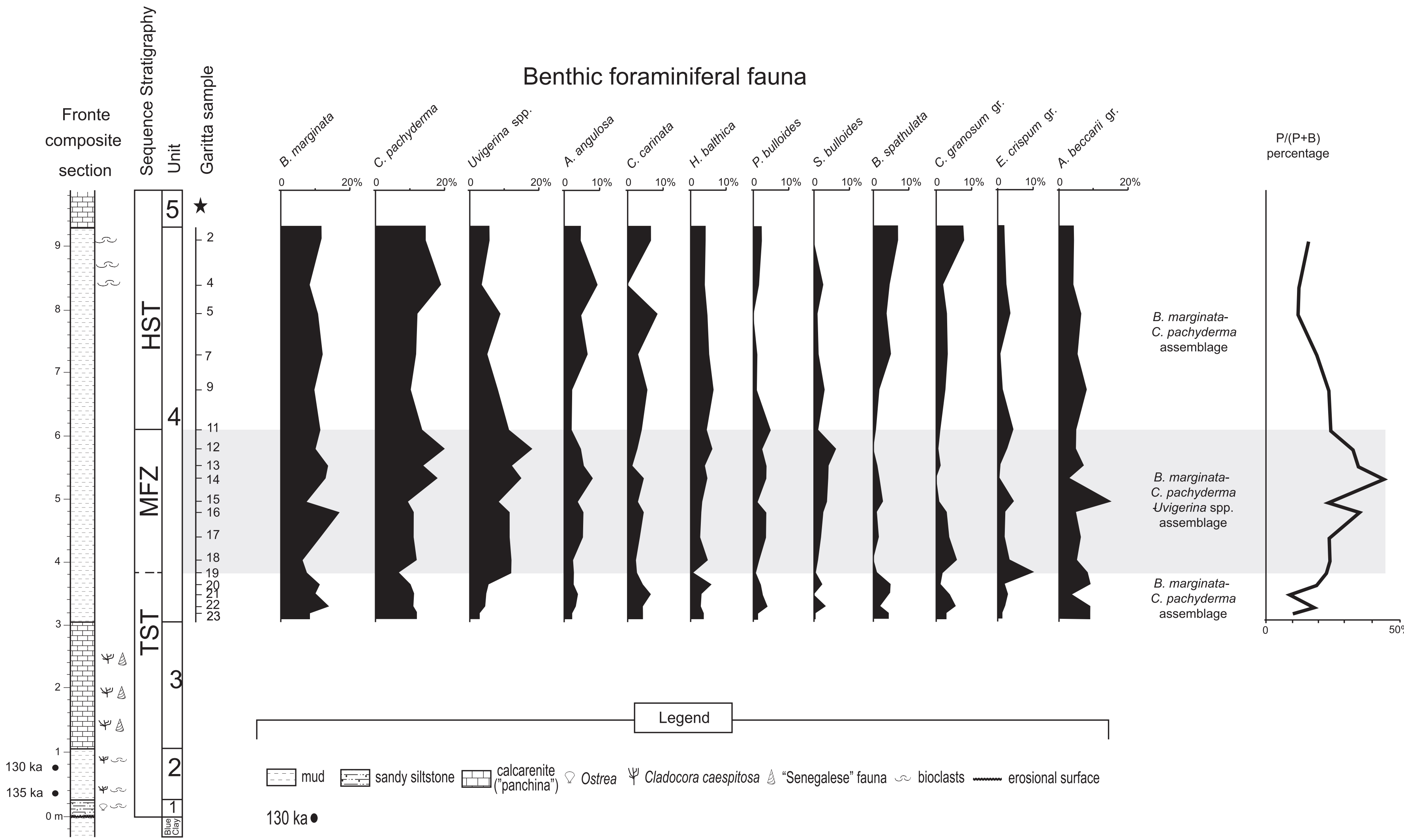

Fig. 4. Lithology, sequence stratigraphic features, and stratigraphic features of the Fronte composite section. The distribution of the most abundant benthic foraminiferal species and planktonic/benthic ratio is shown for the fine grained sediments of unit 4. Units and $^{230}Th/U$ dating (black dots) as described in Amorosi et al. (2014). Black star indicates the extra sample collected from unit 5.

concerning Mediterranean modern assemblages (Thunell, 1978; Jorissen, 1988; Sgarrella and Moncharmont Zei, 1993; Frezza et al., 2005; Murray, 2006; Frezza and Carboni, 2007). Following Van der Zwaan et al. (1990) and Van Hinsbergen et al. (2005), further qualitative paleobathymetric determinations were made using the planktonic/benthic ratio expressed as 100 * P/(P + B).

Stable oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotope ratios were determined on the samples prepared for foraminiferal analyses using a Gas Bench II (Thermo Scientific) coupled with an IRMS Delta XP (Finnigan Mat) at the Institute of Geosciences and Earth Resources at CNR in Pisa (Italy). At least 40 to 50 well-preserved individuals of the benthic foraminifera species *C. pachyderma* were picked in the size fraction >350 μm, soaked in distilled water plus 30% H_2O_2, and cleaned in an ultrasonic bath to remove contaminants such as fine-grained particles and organic matter. Thereafter, the shells were crushed and homogenized. Each carbonate sample of ca. 0.15 mg was dissolved in H_3PO_4 (100%), for 1 h at 70 °C in a sealed vial flushed with helium. The headspace gas (CO_2) was entrained in a helium stream, dried with a Nafion gas dryer, purified by passing through a gas chromatographic column and then injected into the continuous flow isotope ratio mass spectrometer via an active open split. The results were determined relative to the Vienna Pee Dee Belemnite (VPDB) international standard. Sample results were corrected using the international standard NBS-19 and a set of 3 internal standards (two marbles, MOM and MS, and a carbonatite NEW12, previously calibrated using the international standards NBS-18 and NBS-19). Analytical uncertainties for replicated analyses of $\delta^{18}O$ and $\delta^{13}C$ were 0.17‰ and 0.15‰, respectively.

Twelve samples were selected for the study of palynomorphs (pollen and dinoflagellate cysts). Standard methods were used including acid digestion (HCl, HF), sodium hexametaphosphate, concentration techniques ($ZnCl_2$ at density 2.00, sieving at 10 μm), and mounting in glycerol. Acetolysis, oxidation, KOH, and hot acid treatments were avoided in order to prevent damage to certain cysts. The high incidence of barren samples and samples with very low palynomorph concentrations, especially with regard to pollen grains, required the processing of a very large quantity of sediments. For each sample 21.9–39 g of previously dried sediment were weighed and *Lycopodium* tablets were added to determine the palynomorph concentrations. A transmitted light microscope, using ×750 and ×1250 (oil immersion) magnifications, was used for identification and counting of palynomorphs.

Eighteen samples were collected for paleomagnetic analyses in September 2012. Unfortunately, the dryness and friability of the samples led to deterioration in storage, and a full paleomagnetic investigation proved impractical. Instead, 17 unoriented samples from the 6.25-m-thick Garitta section were used for preliminary rock magnetic and paleomagnetic analyses. These analyses were carried out within a magnetically shielded laboratory at the Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome. The low-field and mass-specific magnetic susceptibility (χ) was measured for all samples using an AGICO KLY-2 Kappabridge magnetic susceptibility meter. Natural remanent magnetization (NRM) was measured with an automated pass-through 2G Enterprises cryogenic magnetometer with an in-line alternating field (AF) demagnetizer. Four selected samples were AF demagnetized at successive peak fields of 5, 10, 15, 20, 25, 30, 40, 50, 60, 80, and 100 millitesla (mT). It was not possible to analyze additional samples due to their very poor preservation. Demagnetization results were examined using orthogonal vector diagrams (Zijderveld, 1967), stereographic projections, and intensity decay curves. IRM acquisition and backfield demagnetization of the IRM, hysteresis, and first-order reversal curve (FORC) measurements (Pike et al., 1999; Roberts et al., 2000) were performed on sediment chip samples using a vibrating sample magnetometer (VSM; Princeton Measurements Corporation Model 3900 Micromag). The FORC data processing was performed using the FORCinel package (Harrison and Feinberg, 2008).

3. Results

3.1. Faunal and stable isotope insights

A total of 107 species of benthic foraminifers, belonging to 53 genera, were recognized within the silty marl succession (unit 4 in Fig. 4). This highly diversified assemblage is dominated by the epifaunal/shallow infaunal *B. marginata* and *C. pachyderma*, which show relative frequencies ranging between 6.5% and 20%. *Uvigerina mediterranea* and *Uvigerina peregrina* (lumped as *Uvigerina* spp. in Fig. 4) exhibit an upward increasing-decreasing trend, reaching the highest abundances (about 8–20%) within the middle portion of the studied succession (samples 19–11 in Fig. 4). Among the secondary taxa, remarkable percentages (about 3–7%) of *Angulogerina angulosa*, *Cassidulina carinata*, *Hyalinea balthica* and *Ammonia beccarii* gr. are persistently recorded. Conversely, *Bolivina sphatulata* shows a highly variable trend, with the lowest abundance in the middle portion of the unit (samples 19–11 in Fig. 4). Slightly lower amounts of *Sphaeroidina bulloides*, *Pullenia bulloides*, *Cribroelphidium granosum* gr. and *Elphidium crispum* gr. were also encountered (Fig. 4). Among the rare species, *Gyroidinoides soldanii*, *Neoconorbina terquemi* and *Rosalina bradyi* are the most frequently recorded, with percentages commonly lower than 2.5%.

The planktonic foraminiferal fauna, which is rather scarce throughout the studied succession, consists of *Globigerina bulloides* and *Globigerinoides ruber*, with rare *Orbulina universa* and *Globorotalia inflata*.

As a whole, the benthic foraminiferal association, which mainly consists of species widely reported from the modern Mediterranean circalittoral zones (Sgarrella and Moncharmont Zei, 1993), is indicative of a middle to outer shelf environment (<100 m water depth), characterized by muddy sediments, medium to high trophic levels and limited or no oxygen depletion at the sea floor. In this context, the remarkable amounts of *B. sphatulata*, an opportunistic species tolerant of low oxygenation (Jorissen et al., 1992), suggest the occurrence of moderate dysoxic episodes.

Corresponding to the middle portion of unit 4, the sharp increase of *U. mediterranea* and *U. peregrina*, taxa indicative of high food fluxes with moderate or no oxygen depletion (Jorissen, 1988), is mirrored by an abrupt decrease of *B. sphatulata*, reflecting an improvement of bottom floor oxygenation, probably accompanied by a slight increase in water depth (MFZ). This interpretation is consistent with the long-term decreasing trend of *C. granosum* gr., which is frequently reported from the Mediterranean infralittoral to uppermost circalittoral zones (Sgarrella and Moncharmont Zei, 1993), and the P/(P + B) ratio. The latter significantly increases at the transition to the middle portion of unit 4 (sample 19 in Fig. 4), stabilizing on values greater than 25%. More specifically, the highest values (>35%) are encountered between 170 cm and 300 cm above the lower boundary of unit 4, reaching the peak of 44.9% at sample 14 (Fig. 4). Upwards, the P/(P + B) ratio decreases, showing values similar to those recorded in the lower portion (Fig. 4).

Moreover, despite good shell preservation, local peaks of *A. beccarii* gr. (Fig. 4), commonly abundant in inner shelf areas, suggest sporadic high-energy events pointing to a depositional setting affected by high sedimentation rates. The foraminiferal content indicates the establishment of a stable depositional setting, and oxygen isotopic ($\delta^{18}O$) data from *C. pachyderma* show fairly constant values across the entire marly unit (+2.34 ± 0.14‰), (Fig. 5). This isotopic record is in agreement with the isotopic "plateau" described by Shackleton et al. (2003), found in North

Atlantic and Mediterranean high-resolution cores (e.g. ODP Site 980, Oppo et al., 2006; ODP Hole 963A, Sprovieri et al., 2006) (Fig. 5).

The microfaunal assemblage observed in the one sample from unit 5 is dominated by infralittoral to upper circalittoral species such as *N. terquemi*, and various miliolids, mainly represented by *Sigmoilina costata*. The macrofaunal assemblage is rich, and is dominated by the deep sublittoral bivalve *Gouldia minima*, associated with abundant *Bittium* spp., *Corbula gibba* and *Glycymeris glycymeris*. Additionally, rare specimens of the west African gastropod *Acteocina knockeri* were recovered.

3.2. Palynology

Eight out of 12 samples processed for marine and terrestrial palynology contained sufficient dinoflagellate cysts ("dinocysts") and/or pollen grains to count 100 or more specimens. There is no evidence for reworking of dinocysts. Among the pollen, only an individual reworked pollen grain of *Tsuga* was recorded, in sample 12. Land-derived palynomorphs (Table 1) are represented almost exclusively by pollen grains of *Pinus* which reach the highest concentrations in sample 14 (839 grains per gram dry mass). Other pollen taxa are very scanty and sporadically occurring (e.g. *Abies*, *Carpinus*, Poaceae, Asteraceae Cichoiroideae and Asteroideae; Brassicaceae, Dipsacaceae). Only in the upper sample (2) are fungal remains (e.g. spores, hyphae, and fruiting bodies) exceptionally abundant, along with other terrestrial organic debris. The absence of rich and well-diversified pollen assemblages prevents any inference of the paleoclimatic context; however, the paleoclimate has been thoroughly documented by high-resolution pollen analyses from the very close Monticchio section (e.g. Allen and Huntley, 2009) covering the interval of time between ca. 132.9 ka and ca. 107.6 ka.

Table 1
Palynomorph concentration per gram dry weight of sediment at the Garitta section. Note the very low palynomorphs concentration and species richness. In sample SG12-2 the very high abundance of organic matter prevents the quantitative counting. Asterisk marks the palynomorphs occurrence (see text).

Palynomorphs/samples	SG2-12–2	SG2-12–7	SG2-12–8	SG2-12–12	SG2-12–14	SG2-12–15	SG2-12–18	SG2-12–19	SG2-12–20	SG2-12–21	SG2-12–22	SG2-12–23
Pinus	*	Barren	116.4	483	839	17	136	103	13	22	Barren	Barren
Abies		Barren		13			16				Barren	Barren
Carpinus		Barren							4		Barren	Barren
Tsuga reworked		Barren		6							Barren	Barren
Asteraceae Asteroideae	*	Barren					5				Barren	Barren
Asteraceae Cichorioideae	*	Barren		6		24	10				Barren	Barren
Brassicaceae		Barren				24					Barren	Barren
Dipsacaceae		Barren							4		Barren	Barren
Poaceae		Barren			27				4		Barren	Barren
Impagidinium spp.	*	Barren	19.4	38			26	3			Barren	Barren
Lingulodinium machaerophorum	*	Barren									Barren	Barren
Polysphaeridium zoharyi	*	Barren	233	64		95	380	180	58		Barren	Barren
Spiniferites spp.	*	Barren						3			Barren	Barren

Marine palynomorphs consist exclusively of dinocysts (Table 1). The generally very low concentration, along with some barren samples, indicated taphonomic biases for both pollen grains and dinocysts. Probably most palynomorphs were destroyed prior to or soon after their final deposition. It seems that post-depositional processes related to diagenesis and weathering did not contribute to the degradation of the observed palynomorphs, which generally appear well preserved, despite some apparent mechanical damage (especially *Pinus*, *I. patulum* and *Impagidinium* spp.). However, it is relevant to observe that encountered taxa (*Polysphaeridium zoharyi* and *Impagidinium* spp.) are resistant to aerobic degradation (R-cysts; Versteegh and Zonneveld, 2002). From the base of the section, after barren to virtually barren samples 23–21, from sample 20 onward, oligotypic (to monotypic) dinocyst assemblages show the peculiar occurrence of *P. zoharyi*, the resting cyst of the toxic marine dinoflagellate *Pyrodinium bahamense*. *P. zoharyi*, which is typical of warm waters in tropical/subtropical coastal/lagoonal sites (Marret and Zonneveld, 2003), shows its highest concentrations in samples 19 (180 cysts per gram dry mass), 18 (350 cysts per gram dry weight), 8 (233 cysts per gram dry mass) and 2 (229 cysts per gram dry mass). Previous palynological studies from seven eastern Mediterranean sediment cores pointed out the peculiar abundance values of *P. zoharyi* during the deposition of Sapropel S5 (cores BD02-GC01, SIN97-GC01, BAN89-GC09, Giunta et al., 2006, Fig. 6). In such sites, the abundance of *P. zoharyi* differed with the increasing stratification of near-surface waters eastwards. There, *P. zoharyi* along with *L. machaerophorum* (a species sporadically present here) were present only in the lower part of the sapropel S5 in the northwestern core, while they increased in the central and/or in the upper parts of the sapropel in the two other, easternmost cores. Other dinocysts (i.e. *Impagidinium* spp. and *Spiniferites* spp.) are highly scattered; nevertheless, the occurrence of *I. patulum* in particular (sample 19) helps in understanding the main environmental changes. *I. patulum*, a typical temperate to tropical oceanic species, although probably an allochthonous element in the Garitta assemblages, attests to a major expansion of open marine settings related to the MFZ. At the top of unit 4, the large abundance of fungi and organic land-derived non-pollen palynomorphs indicates a strong increase in terrestrial input. However, only sporadic pollen grains of *Pinus* and Asteraceae were recovered, together with sparse dinocysts, whose occurrence could not be quantified due to their very rare occurrence (their presence is marked by an asterisk in Table 1) with respect to the quantity of the added *Lycopodium* and organic matter. Such conditions, along with the absence of palynomorphs in sample SG12-7, currently prevent reliable paleoenvironmental inferences for the upper portion of the section.

3.3. Paleomagnetism

The paleomagnetic measurements gave NRM intensities ranging from 4.9 to 12 $\mu A\ m^2\ kg^{-1}$ and low-field magnetic susceptibilities from 25.9 to 93.9 $\times\ 10^{-8}\ m^3\ kg^{-1}$. The magnetic susceptibility follows an increasing trend in the upper part of the stratigraphic section, with a prominent peak at 420–450 cm from the base, probably due to increased detrital input.

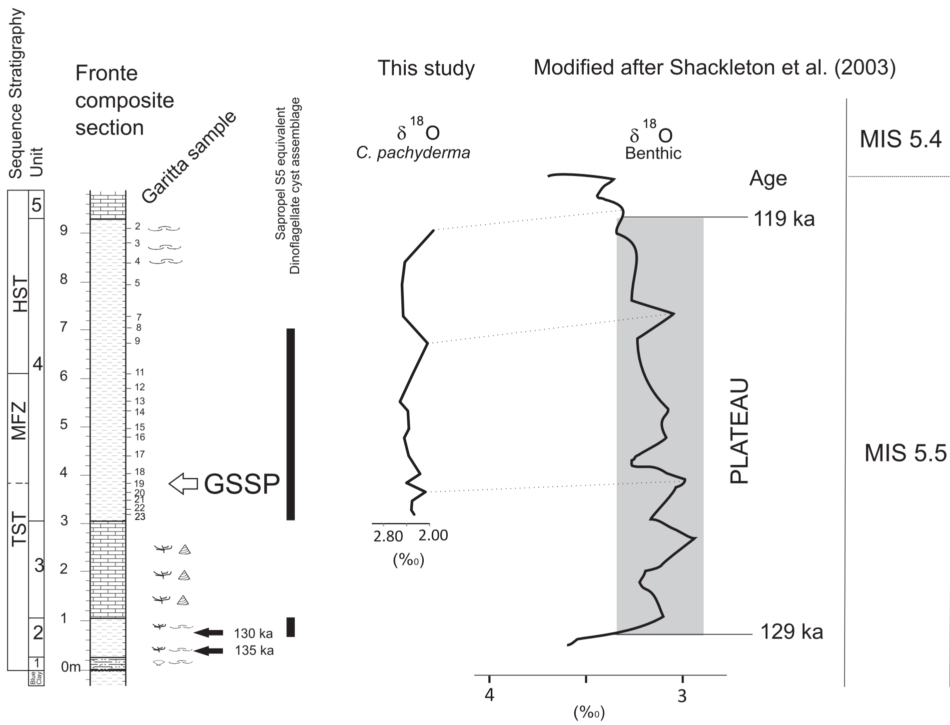

Fig. 5. Oxygen stable isotope stack and occurrence of Sapropel S5 dinocyst assemblage black vertical bar (Unit 4, data from present paper; Unit 2, data according to Amorosi et al., 2014) at the Fronte composite section. Dashed lines indicate a tentative correlation of the most evident peaks in the MIS 5.5 plateau of Shackleton et al. (2003). Black arrows indicate U–Th ages. White arrow indicates possible position of GSSP. For lithology legend, see Fig. 4.

The demagnetization diagrams show a well-defined characteristic remanent magnetization (ChRM), completely removed at AF strengths ranging from 40 to 60 mT. These results indicate that high-coercivity minerals such as hematite are absent and that AF demagnetization can be used to investigate the polarity zonation of the Garitta section.

The presence of a low-coercivity mineral phase, as indicated by the AF demagnetization behaviour, was confirmed by IRM acquisition and backfield demagnetization of the IRM. The FORC distribution for sample SG12-13 lies close to the origin of the FORC diagram, with a slight peak at ~20 mT representing the signature of single domain (SD) grains (Fig. 7). The small divergence and the triangular shape of the outer contours indicate a small contribution from the pseudo-single domain (PSD) grains to the magnetic properties of this sample (Roberts et al., 2000; Pike et al., 1999). A large peak at the origin of the FORC distribution in both samples, most easily seen in profiles along the B_c axis, indicates a significant reversible component of magnetization due to paramagnetic and superparamagnetic (SP) components. The SP contribution (estimated at around 4.5%) was established by analysis of the viscous decay ($\Delta t = 100$ s) of an imposed 1 T IRM. This technique has previously been applied by Wang et al. (2010). It thus appears that in addition to SD and PSD grains, the sample contains a substantial population of SP grains, which causes the FORC distribution to shift to lower coercivities.

4. Discussion

4.1. Unit 4: a possible candidate for the Upper Pleistocene GSSP

Our foraminiferal data demonstrate that unit 4 is a marine sedimentary record of relatively stable sea-level conditions. The dinocyst assemblages show important similarities with the assemblages reported by Giunta et al. (2006) and Sangiorgi et al. (2006) from the Mediterranean deep-sea as the sedimentary expression of the MIS 5.5 peak: Sapropel S5 (Rohling and Hilgen, 1991; Lourens, 2004).

All these data and the constant stable isotope values, which are in agreement with the plateau reported by Shackleton et al. (2003), strengthen the assignment of the studied section to MIS 5. In particular, the occurrence of *P. zoharyi* provides a strong time constraint to the S5 interval (Giunta et al., 2006). Bar-Matthews et al. (2000) estimated the interval of time represented by this sapropel at 6 ka and Lourens (2004) dated its midpoint to 124 ka. This suggests a time interval bracketed within 127 and 121 ka for the stratigraphic interval between unit 2 and the MFZ detected in unit 4.

This evaluation is consistent with the vertical stacking of facies recorded at the Fronte composite section specifically with the superposition of unit 4 on the fossiliferous calcarenite (unit 3) bearing the "Senegalese" fauna, which is known to reflect generalized warm conditions related to the last interglacial. In terms of sea-level fluctuations, unit 3 has recently been interpreted (Amorosi et al., 2014) as deposited after the first pulse and subsequent sea-level stabilization, recorded by Hearty et al. (2007) at around 130–125 ka. The well-defined deepening-upward tendency (including the maximum flooding surface) recorded above the rapid transition from unit 3 to unit 4 is probably correlative with the second rise in sea level reported by Hearty et al. (2007), when global sea level reached its highest sea-level position during the last interglacial (Kukla et al., 2002; Shackleton et al., 2002, 2003). These two pulses are chronologically constrained in the Lisiecki and Raymo (2005) $\delta^{18}O$ stack, and dated to 123 and 126 ka, respectively. This fits well with the ages of the base and top of Sapropel S5.

At this point, a simple exercise in estimating sedimentation rates may suggest hypotheses about the time interval represented in the Section. A first consideration comes from thickness of units 2 and 3. These two units include *in situ Cladocora* colonies, except for the uppermost 40 cm of unit 3, which contain only fragments of this coral. According to Peirano et al. (2009) the growth velocity of modern *Cladocora* is 4.2 mm/y on average. This allows us to estimate less than 1000 years for the deposition of units 2 (where

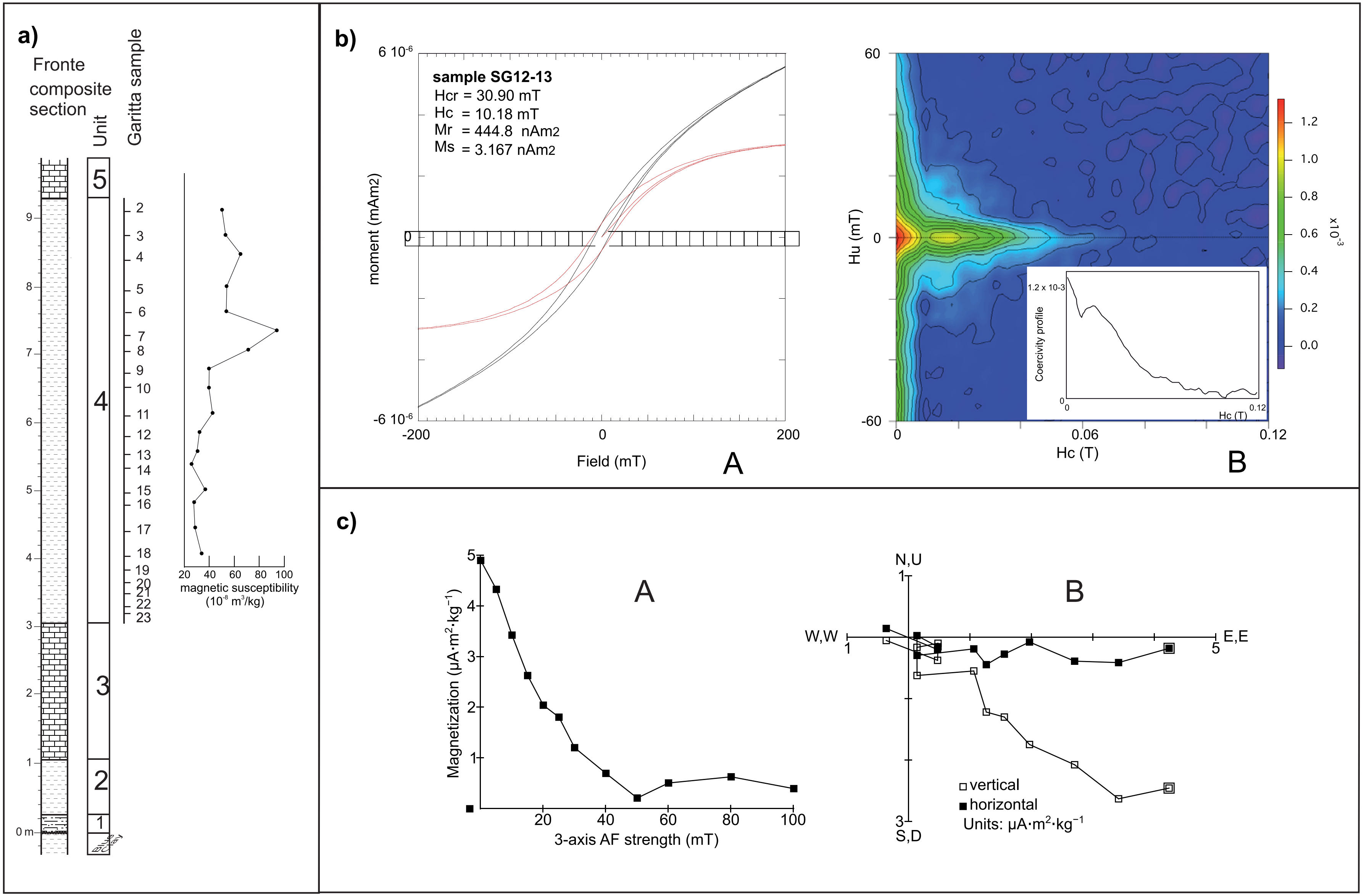

Fig. 6. Paleomagnetic data. (a) Stratigraphic variation of low-field mass-specific magnetic susceptibility. (b) AF demagnetization results for sample SG12-13, showing behaviour typical of the studied samples. Graph A shows remaining sample magnetization plotted against AF strength; graph B is an orthogonal vector component diagram (Zijderveld, 1967). Demagnetization vectors trend towards the origin and almost all magnetization is removed by the 50 mT step. Plots produced with PuffinPlot (Lurcock and Wilson, 2012). (c) hysteresis loop before (A) and after (B) slope correction for paramagnetic contribution and first order reversal curve (FORC) diagram for sample SG12-13 (smoothing factor 6) with inset horizontal coercivity profile through the peak of the central ridge that dominates the FORC distribution. The slight peak at ~20 mT is a typical signature of single-domain (SD) grains. The small divergence and the triangular shape of outer contours indicate a small contribution from the pseudo-single-domain (PSD) grains. The large peak at the origin of the FORC distribution indicates a significant reversible component of magnetization due to paramagnetic and superparamagnetic (SP) components.

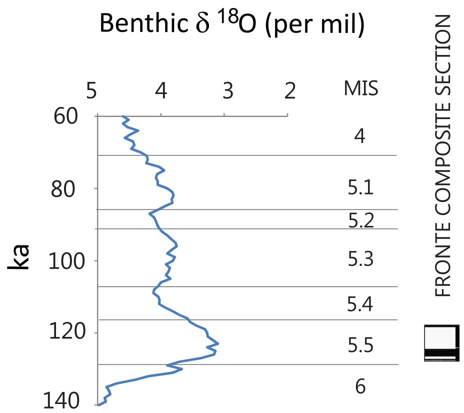

Fig. 7. Temporal position of the Fronte composite section and correlation to MIS 5.5. Benthic $\delta^{18}O$ from Lisiecki and Raymo (2005).

U—Th ages obtained from *Cladocora* range between 135 and 130 ka) and 3, showing a thickness of about 3 m. We can also speculate that this growth took place during the first sea-level pulse, peaking at 126 ka.

Unit 4 is 6.25 m thick, and we identified the MFZ (marked by a clear increase in the foraminiferal P/B ratio ratio and changes in benthic foraminiferal fauna composition, Fig. 4) between 0.7 and 3 m from the base; this allows us to correlate the midpoint (1.9 m) to the second pulse of sea-level rise dated at 123 ka (Lisiecki and Raymo, 2005). In spite of possible changes in sedimentation rate as a function of different systems tracts (see Scarponi et al., 2013) we hypothesize a tentative mean sedimentation rate of 300 mm/ky for continental shelf deposits (Gross, 1972). This implies an interval of time of 14.5 ky for sedimentation of the remaining 4.35 m of unit 4. This would assign an age of 109.5 ka to the top of unit 4, suggesting that unit 4 also comprises MIS 5.4, the peak of which has been dated at 109 ka (Lisiecki and Raymo, 2005). This hypothesis, however, does not fit with our isotopic data, which are consistent with the plateau reported by Shackleton et al. (2003). This indicates that unit 4, if continuously deposited above the *Panchina* of unit 3, would correlate to MIS 5.5. If unit 4 records the isotopic “plateau” described by Shackleton et al. (2003), we can consider it to represent approximately the time period 129–116 ka (^{230}Th/U dating of marine terrace highstand used by Shackleton et al., 2003 to date this plateau). The beginning of the plateau is considered older (ca. 133 ka) by Drysdale et al. (2009), and is probably represented in unit 2. However, due to the unfavorable sedimentary facies which yielded insufficient benthic foraminifera for stable isotopic analyses, we were not able to locate this datum. Instead, we can assume that the end of the “plateau” in Shackleton et al. (2003 and Fig. 5) is probably correlative with the uppermost deposits of unit 5. Indeed, the presence within unit 5 of a characteristic species of subtropical affinity (*A. knokeri*), agrees well with the placement of the uppermost calcarenite in MIS 5.5. The mollusc and foraminiferal fauna (see above) found within this unit indicate a water depth of 30—60 m (Sgarrella and Moncharmont Zei, 1993) with an overall shallowing-upward trend, culminating in the calcarenite deposition at the Fronte outcrop. In terms of sequence stratigraphy, this uppermost portion of unit 4 and unit 5 represents an episode of progradation (highstand systems tract) probably occurring at the end of the “plateau” of Shackleton et al. (2003) (see Fig. 5). In this case, we can hypothesize a time interval about 7 ky for a 4.35 m-thick unit, resulting in a sedimentation rate of about 621 mm/ky. This value is very high, but is consistent with older data (Parenzan, 1969) and recent sedimentological studies from the Mar Piccolo area (Mastronuzzi, pers. comm), highlighting *a* > 5 m-thick Holocene succession and thus comparable sedimentation rates. We could also speculate that the erosional surface at the top of unit 5 represents the last record of the dramatic sea-level drop used by Shackleton et al. (2003) to trace the boundary between MIS 5.5 and 5.4 (see Fig. 5).

The hypothesis that we can find a sedimentary expression of sea-level shallowing at the end of MIS 5.5 seems to be in contrast with the sea-level trend (Waelbroek et al., 2002; Siddall et al., 2003). However, two facts should be considered: 1) accuracy in sea-level reconstructions from the Mediterranean area is limited by the lack of coral reefs able to provide a continuous, well dated, sea-level trend, such as the one described from Barbados (Bard et al., 1990) or New Guinea (Cutler et al., 2003), as well as by the lack of isostatic models for MIS 5 (Antonioli and Furlani, 2012).; 2) sea-level fall is slower than sea-level rise, and the negative peak of −42 m during MIS 5.4 was reached after a longer interval of time. Thus, we suggest that the facies change to the fossiliferous calcarenite (unit 5) at the Fronte composite section is consistent with the inception of the inversion in sea-level trend toward the end of the plateau described in Shackleton et al. (2003) (Fig. 7).

It is noteworthy that, after Dai Pra and Stearns (1977), Hearty and Dai Pra (1992) also described the occurrence of a discontinuity above the fossiliferous calcarenites of unit 3, but described unit 4 as marine MII (Marine II). They correlated this unit to Aminozone E based on *Glycymeris*, dated at 85 ka (i.e., MIS 5.1, which according to Waelbroek et al. (2002) and Siddall et al. (2003) should indicate sea level at −21.2 m and −26.7 m, respectively), and hypothesized a discontinuity marking the transition to more recent marine isotopic substages.

Conversely, we demonstrate that the upper part of the MIS 5.5 succession is fairly complete at the Fronte composite section, and that the continuous marine sedimentary succession we have documented provides a continuous, stable, pelagic facies of convenient duration for the definition and placing of a GSSP. As can be seen in Fig. 8, this interval can be correlated to the Mediterranean deep sea cores in which MIS 5.5 is identified through the stable isotope detection of marine isotope stages, or to Eastern Mediterranean cores by the occurrence of sapropels.

Several sections have been described from the Taranto surroundings (see also description of Upper Pleistocene outcrops in Dai Pra and Stearns, 1977; Belluomini et al., 2002). However, the Fronte outcrop is unique, as only in this locality has a thick pelitic interval (unit 4) been preserved. In addition, according to our reconstruction, the MFZ recorded in unit 4 correlates to the MIS 5.5 peak and falls above a ^{230}Th/U dated lithological unit containing the “Senegalese” fauna (*P. latus*).

These promising features, along with the section's continuity, uniformity of facies, lithologic type, accessibility, and location in a fairly stable area, would make the Fronte outcrop a suitable host for the Upper Pleistocene GSSP which could be located at the base of the MFZ recorded in unit 4 of the Fronte composite section (Fig. 5). As the sediments are paleomagnetically promising and a high sedimentation rate is inferred, paleomagnetic analyses are crucial. It is likely that high-resolution paleomagnetic sampling, or a continuous core through the section, would result in identification of short-lived events, such as the Blake geomagnetic excursion. This event was one of the first excursions to be discovered in the Brunhes Chron (Smith and Foster, 1969), and remains one of the most well-established and accurately dated, with a current best age determination of 123 ± 3 ka (Lund et al., 2006). The paleomagnetic location of this event in the section would thus allow precise correlation to the paleomagnetic timescale, fulfilling all the requirements for a GSSP.

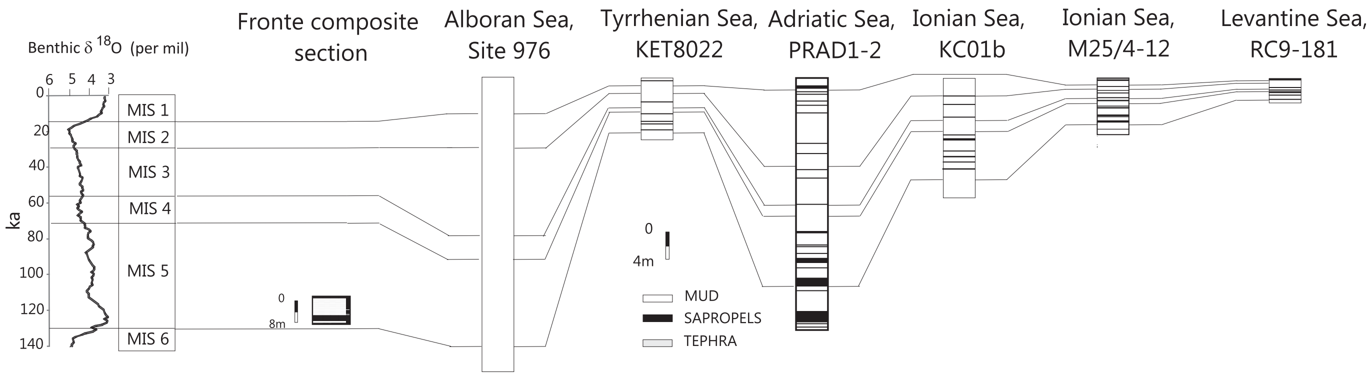

Fig. 8. Correlation of the interval recorded at the Fronte composite section (thickness not to scale) to selected Mediterranean deep-sea cores: ODP core 976 in the Alboran Sea (Comas et al., 1996), core KET 80–22 in the Tyrrhenian Sea (Tucholka et al., 1987), core PRAD 1–2 in the Adriatic Sea (Piva et al., 2008 a,b), core KC01B (Castradori, 1993; Lourens, 2004) and M25/4 12 (Negri et al., 1999) in the Ionian sea, and core RC 9–181 in the Levantine Basin (Vergnaud-Grazzini et al., 1977; Hilgen, 1991).

5. Conclusions

The Fronte composite section is located in an area with a very low rate of uplift, as indicated by the position of the paleocoastline relative to MIS 5 and MIS 11. The section exhibits, above a regional unconformity, the MIS 5.5 deposits as a continuous sedimentary succession characterized by an overall deepening-upward trend, from nearshore to inner-shelf (*Cladocora*-rich) and then middle to outer-shelf deposits.

Above the *Cladocora*-rich units, open-marine clays including the maximum flooding zone show a continuous succession of marly clays, 6.25 m thick (unit 4). New stable isotopic, foraminiferal and palynological data from this stratigraphic interval, coupled with the ^{230}Th/U age, indicate that the whole MIS 5.5 plateau (*sensu* Shackleton et al., 2003), up to the onset of the following sea-level fall, occurs in this section. Preliminary paleomagnetic results from a limited number of samples demonstrate that the sediments are unaffected by remagnetization, thus suggesting their suitability for a complete paleomagnetic study. These promising features, along with the section's continuity, uniformity of facies, lithologic type, accessibility, and location in a fairly stable area, would make the Fronte outcrop a suitable host for the Upper Pleistocene GSSP which we suggest could be positioned at the base of the MFZ as recorded in unit 4 of the Fronte composite section.

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